American Journal of Medical Genetics 65:60–67 (1996)

Monosomy 1p36.31–33→pter Due to a Paternal Reciprocal Translocation: Prognostic Significance of FISH Analysis

Elisabeth Blennow, The-Hung Bui, Anders Wallin, and Per Kogner

Department of Molecular Medicine, Clinical Genetics Unit (E.B., T.-H.B.), Department of Woman and Child Health (A.W., P.K.), and Department of Laboratory Medicine (P.K.), Karolinska Institute, Stockholm, Sweden

A rare monosomy 1p36.31–33→pter was found in a child with physical anomalies, psycho-motor retardation, and seizures. Cytogenetic investigation suggested an unbalanced translocation between 1p and an acrocentric chromosome, but the rearrangement was difficult to assess accurately using conventional chromosome banding techniques. The half-cryptic translocation was further characterized using fluorescence in situ hybridization, and the aberrant chromosome 1 was shown to be a derivate of a paternal reciprocal translocation t(1;15)(p36.31–33;p11.2–12). The breakpoints on chromosome 1 and 15 were defined in detail using locus specific probes. The rearrangement did not include the region on chromosome 1p which previously has been suggested to predispose to the development of neuroblastoma in a case with a constitutional translocation. At 3$^{9}/_{12}$ years, the patient has no clinical signs of this disease, which illustrates the prognostic significance of this investigation.

KEY WORDS: reciprocal translocation, neuroblastoma, fluorescence in situ hybridization

INTRODUCTION

Constitutional partial monosomy of chromosome 1p is rare. It includes interstitial and terminal deletions of varying sizes and with different breakpoints [Howard and Porteus, 1990; Keppler-Noreuil et al., 1995], as well as rearranged products of familial or de novo translocations involving the short arm of chromosome 1 [Hain et al., 1980; Yunis et al., 1981; Desangles et al., 1983; Steele et al., 1984; Abbas et al., 1990; Barbi et al., 1992]. For these reasons, a specific phenotype has been difficult to delineate.

We here report an additional case with a very small terminal deletion of 1p resulting from a paternal reciprocal translocation. The breakpoint on chromosome 1p was defined in detail using fluorescence in situ hybridization (FISH).

CLINICAL REPORT

The proposita was the second child of healthy nonconsanguineous parents. She was delivered by emergency caesarean section due to abruptio placentae in the 41st week of gestation. The pregnancy was otherwise uneventful. Birth weight was 2,725 g and length was 48 cm. At 3 days, a large fontanelle, transient sunset phenomenon, and jitteryness were noted. Ultrasonography of the brain was normal. During the following weeks, a rapid catch-up of all growth parameters was noted. At 6 weeks, generalized tonic clonic seizures were observed. EEG showed sporadic epileptogenic potentials over the left cerebral hemisphere and clinical improvement followed after phenobarbital treatment. At 5 months development appeared to be normal and the antiepileptic treatment was reduced, but when reexamined at 8 months her development was obviously retarded; she had poor eye contact, her eyes were deep set and amaurotic, and she had autistic behavior as well as feeding difficulties. Repeated series of BNS (Blitz, Nick, und Salaam) seizures were observed. EEG showed bilateral epileptogenic activity but no hypsarrhythmia was registered. Phenobarbital, valproic acid, and ACTH treatment had no effect on the convulsions. CT-scan and MRI of the brain at 9 and 10 months of age, respectively, could not demonstrate any significant abnormality. Brainstem auditory evoked potentials showed deafness on the right side and reduced hearing on the left side. Ophthalmological examination supported the suspicion of impaired vision.

At 2 years her vision had improved with better eye contact. She had generalized muscular hypotonia, a prominent forehead with frontal bossing, and deep set

Received for publication August 18, 1995; revision received November 20, 1995.

Address reprint requests to Dr. Elisabeth Blennow, Department of Clinical Genetics, Karolinska Hospital, S-171 76 Stockholm, Sweden.

eyes. The eyes no longer appeared amaurotic (Fig. 1). The ears were low set and abnormally modeled; the mouth was small with down-turned corners. She also had manual apraxia, twisting her hands in a washing maneuver. The diurnal rhythm was abnormal with irregular, short periods of sleep and series of seizures upon awakening. She could crawl but not walk, and she moved by rolling on the floor.

At 3 6/12 years of age the proposita was less hypotonic; she could sit without support and walk using a walking chair. Mild scoliosis was noted. With correction glasses she could see objects within 0.5 m. There was no speech but she could use nonverbal communication. She had almost daily absences and akinetic seizures. The manual apraxia persisted. CT scan of the brain, chest roentgenogram, abdominal ultrasonography, MIBG (meta-iodobenzylguanidine)-scintigraphy, catecholamines and their metabolites in urine, and neuropeptide-Y concentrations in plasma were all normal.

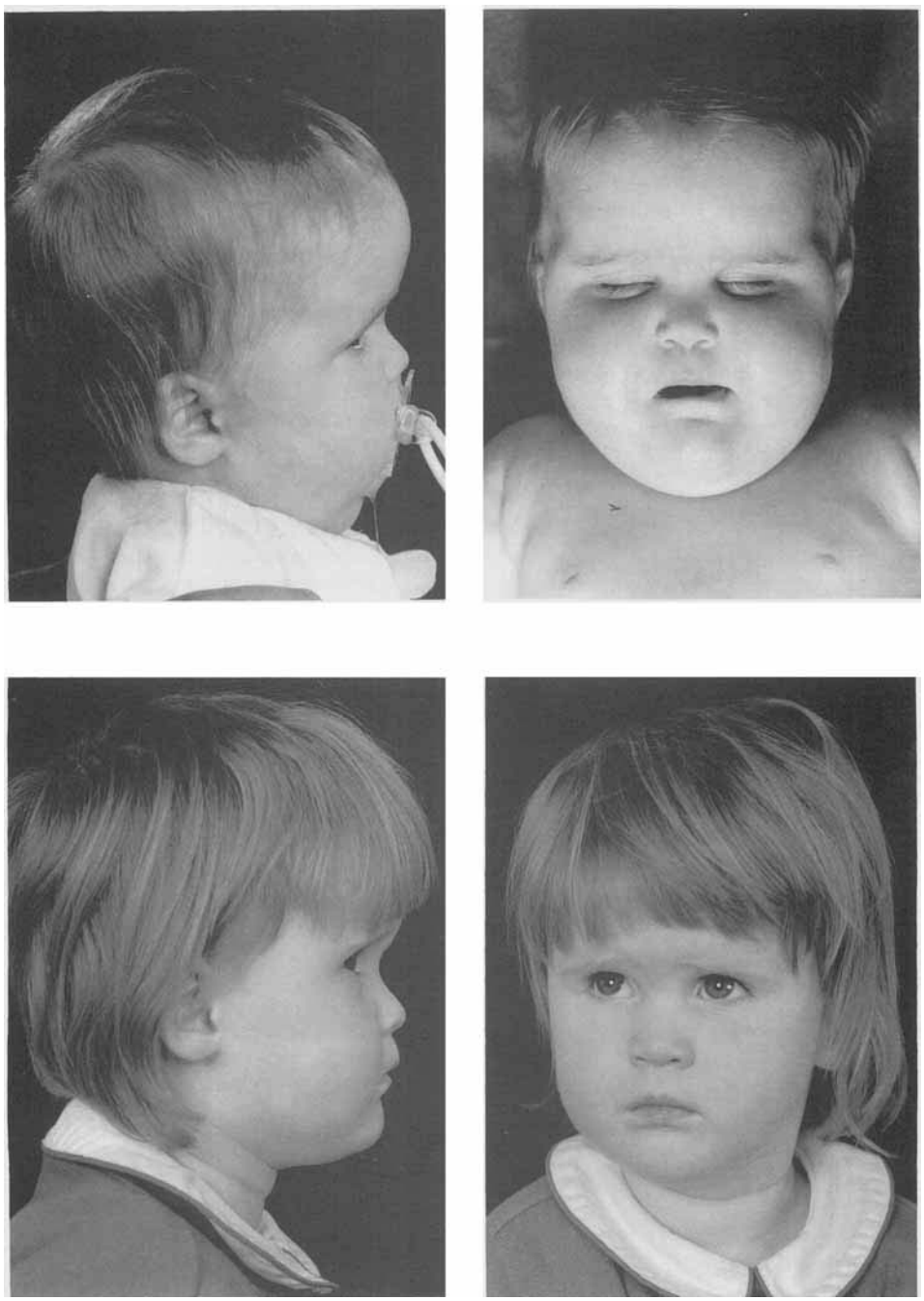

Fig. 1. Photographs of the patient at 8 months (top) and 2 years of age (bottom).

CYTOGENETIC STUDIES

Metaphase slides were prepared from lymphocyte (proposita, both parents, and grandparents) and fibroblast cultures (proposita). GTG-, QFQ-banding, AgNOR, and DA/DAPI staining were performed using standard procedures.

FISH

The chromosome slides were fixed in methanol:acetic acid (3:1) for 40 minutes, in aceton for 10 minutes, and then air dried. The chromosome specific library PCR-1 was labeled with biotin-16-dUTP (Boehringer Mannheim, Scandinavia AB, Sweden) by PCR. The cosmids PND 12A, D1S47 [van Roy et al., 1993], D1S160 [Engelstein et al., 1993], and the repetitive probe D1Z2 [Buroker et al., 1987; van Roy et al., 1993] were labeled with biotin-16-dUTP by nick translation. The location and order of the probes is indicated in Figure 2.

The probes were separately hybridized in 50% formamide, 2×SSC, 50 mM phosphate buffer, pH 7.0, at a probe concentration of 4–5 ng/μl. In addition, 2–3 mg Cot-1 DNA (Giblo BRL, Gaithersburg, MD) was added to the probe mixture. After denaturation at 75°C for 5 minutes, the probe mixture was left to prehybridize at 37°C for 1 hour. Before adding the probe mixture to the slide, 1 μl of the centromere specific probe D15Z1, labeled with fluoro red-dUTP (Amersham), was added. Hybridization was performed in a moist chamber at 37°C overnight. The slides were then washed three times for 5 minutes in 50% formamide, 2×SSC at 42°C and twice in 2×SSC at 42°C (the cosmids once for 5 minutes in 2×SSC at 72°C).

Probe detection and signal amplification were performed by applying two alternating layers of fluorescein-avidin DCS (Vector Lab, Burlingame, CA) and biotinylated anti-avidin antibodies (Vector Lab). After dehydration, the slides were mounted in glycerol containing 2.3% DABCO (1,4-diazabicyclo-(2,2,2) octane) as antifade, and DAPI (4,6-diamino-3-phenyl-indole) at 0.5 μg/ml as counterstain of the chromosomes.

The signal was visualized using a Zeiss Axiophot fluorescence microscope equipped with cooled CCD-camera (Photometrics Nu 200/CH 250), controlled by a Macintosh Quadra 950 computer. Gray scale images were captured, pseudocolored, and merged using the SmartCapture software (Digital Scientific, Cambridge, UK).

RESULTS

Cytogenetic studies of the proposita at 10 months of age showed that the distal part of one chromosome 1p appeared to be satellited by QFQ- and GTG-banding (Fig. 3). It was subsequently shown to be AgNOR positive, suggesting an unbalanced reciprocal translocation involving one of the acrocentric chromosomes. Chromosome analysis of the parents showed the same rearranged chromosome 1 in the father, while the mother had a normal karyotype. In the proposita, one G-group chromosome was AgNOR negative, whereas in the father, one D- and one G-group chromosome was negative, making these results inconclusive as to the origin of the acrocentric chromosome involved in the translocation. DA/DAPI staining was normal in both cases, with no staining of distal 1p. Subsequent investigation of the grandparents demonstrated the translocation in the paternal grandmother.

FISH using a chromosome 1-specific library showed labeling of both chromosomes 1 except the tip of one 1p in both the proposita and her father (Fig. 4a,b). In the

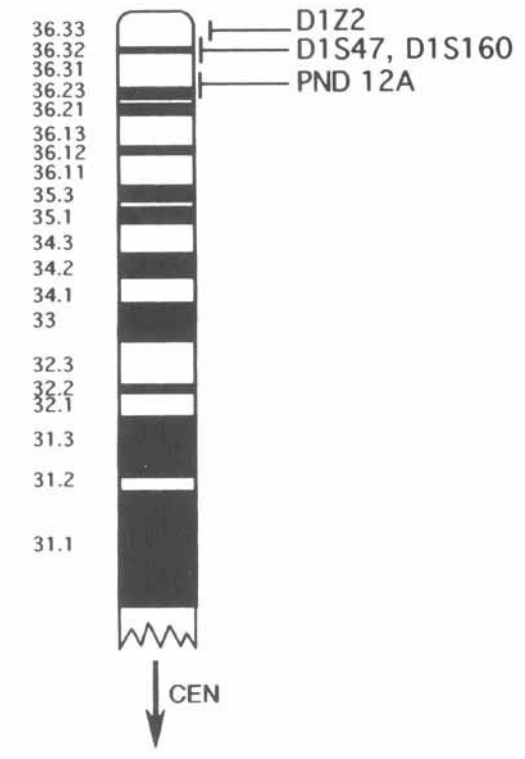

Fig. 2. Partial ideogram of the short arm of chromosome 1, indicating the localization of the locus-specific probes used in this study.

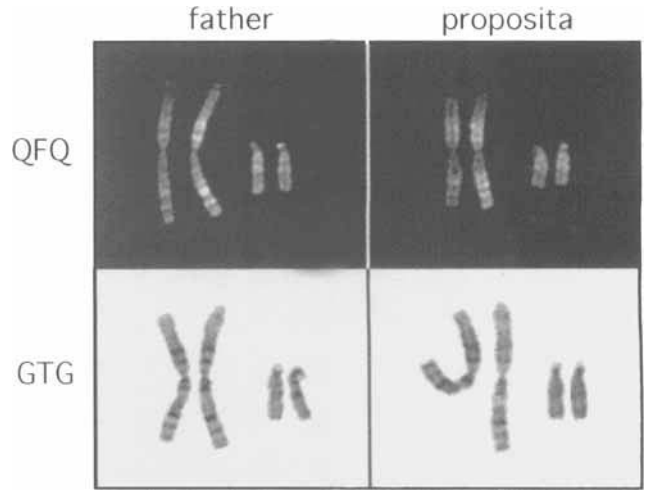

Fig. 3. Partial karyotypes of the proposita and her father, showing the QFQ- and GTG-banded chromosomes 1 and 15.

proposita no other chromosome was labeled, but in the father, a hybridization signal on the tip of the p-arm of a D-group chromosome was noted (Fig. 4b). This was shown to be chromosome 15 by subsequent QFQ-banding of the same metaphase. The pericentromeric probe D15Z1, containing satellite III sequences, was retained on chromosome 15 in both cases, thereby defining the breakpoint on chromosome 15 to p11.2–12, in agreement with the DA/DAPI results. The breakpoint on chromosome 1p was defined using three cosmid probes localized between 1p36.23–1p36.33 and a repetitive probe assigned to 1p36.33 (Fig. 2). All three cosmids (PND12A, D1S160, and D1S47) were retained on chromosome 1p (Fig. 4c–e), whereas the D1Z2 signal was translocated to chromosome 15p (Fig. 4f). Hence, the breakpoint could be located between D1S47 and D1Z2. The distance between these proes has been estimated to 28 cM [NIH/CEPH Collaborative Mapping Group 1992].

Consequently, the complete karyotype of the father was 46,XY,t(1;15)(p36.31–33;p11.2–12)mat, and that of the proposita 46,XX,−1,+der(1)t(1;15) (p36.31–33; p11.2–12) pat, i.e., an adjacent 1 2:2 segregation, resulting in a deletion of 1p36.31–33→pter in the child.

DISCUSSION

In this paper we present a child with a constitutional deletion of 1p36.31–33→pter. Ten additional cases with terminal deletions of 1p36 have hitherto been published [Hain et al., 1980; Yunis et al., 1981; Desangles et al., 1983; Steele et al., 1984; Abbas et al., 1990; Barbi et al., 1992; Keppler-Noreuil et al., 1995]. Seven of these originated from different reciprocal translocations, and in five of them, the breakpoint could not be assigned to a subband. Hence, any phenotypic differences may reflect the varying size of the deletion in those cases. Furthermore, in four cases [Hain et al., 1980; Desangles et al., 1983; Abbas et al., 1990], some of the symptoms may be caused by the concurrent partial trisomy of the other chromosome involved in the rearrangement. It is also noteworthy that 6 out of 11 cases (including the present report) involved a translocation between chromosome 1p and an acrocentric chromosome, which in four cases was chromosome 15. One might speculate that the hypervariable, repetitive region on 1p36.3 [Buroker et al., 1987] may predispose to breaks and rearrangements involving other repetitive regions such as those located on the p-arms of the acrocentric chromosomes. Three cases were reported to have de novo terminal deletions of 1p [Keppler-Noreuil et al., 1995]. However, the deleted chromosomes were only examined using classical cytogenetic methods and the possibility of another type of rearrangement, e.g., a small unbalanced translocation, was not excluded. Nevertheless, all ten patients, as well as the present case, showed many manifestations in common that may be assigned to pure deletion of 1p36 (Table I). The most characteristic dysmorphic signs were deep set eyes, often combined with other ocular anomalies like optic atrophy or coloboma, low set and dysplastic ears, a flat or depressed nasal bridge, a prominent forehead, and a flat occiput. The psycho-motor development was retarded as was the growth in most cases. Hypotonia was a consistent finding and ventricular dilatation or hydrocephalus as well as seizures was reported in a few cases. Patients with a similar clinical picture have also been briefly described in a few conference abstracts [Magenis et al., 1987; Wexler et al., 1991; Howard-Peebles and Black, 1994; Reish et al., 1994].

Genes located on distal 1p have been suggested to play a role in the development of tumors such as meningioma [Bello et al., 1994], colon carcinoma, melanoma, breast cancer and neuroblastoma, a childhood tumor of the sympathetic nervous system [Caron et al., 1993]. Recently, indications for at least two neuroblastoma tumor suppressor genes on chromosome 1p have been presented based on analysis of chromosomal deletions in tumors [Schleiermacher et al., 1994; Takeda et al., 1994] and cell lines [Cheng et al., 1995] as discussed in detail by Versteeg et al. [1995]. The distal gene has been located by deletion mapping in tumor DNA, as distal to 1p36.2 by Southern blot analysis [Caron et al., 1995], and using microsatellites as between D1S244 and D1S80, involving D1S160 [Martinsson et al., 1995].

Only two patients with neuroblastoma and constitutional rearrangements involving 1p36 have been reported. Biegel et al. [1993] reported a dysmorphic child with developmental and growth delay who developed neuroblastoma at 5 months of age. Cytogenetic investigation showed an interstitial deletion of 1p36, which was assumed to predispose the patient to the development of neuroblastoma, and supported the localization of a neuroblastoma tumor-suppressor locus to this region. Southern blot analysis demonstrated a constitutional loss of the maternal allele at D1S47, but retention of both alleles at D1Z2. The other case was a boy with height and head circumference above the 95th centile for age and a constitutional de novo reciprocal translocation t(1;17)(p36;q12–21) who developed neuroblastoma at 9 months of age [Laureys et al., 1990]. In this case, the hypothesis was that the breakpoint disrupted or deleted a gene involved in neuroblastoma development. The breakpoint was later refined by molecular characterization to 1p36.21–36.31, proximal to PND [Laureys et al., 1995] and was shown to disrupt a cluster of small nuclear RNA U1 and tRNA genes [van der Drift et al., 1995].

Using FISH and locus-specific probes, the breakpoint of the terminal deletion in the present case could be localized to 1p36.31–1p36.33 between D1Z2 and D1S47. Therefore, the deletion is clearly distal to the translocation breakpoint as described by Laureys et al. [1995].

Fig. 4. (See overleaf.) Partial metaphases from the proposita (a) and her father (b–f). The chromosome 1-specific library hybridizing to both chromosomes 1 of the proposita, excluding the tip of one p-arm (**a**). The same hybridization-pattern in the father, and in addition the tip of 15p is labeled (**b**). Hybridization using the locus-specific probes PND12A (**c**), D1S160 (**d**), D1S47 (**e**), and D1Z2 (**f**) giving a yellow signal. The centromere of chromosome 15 is labeled in red (d–f) using the pericentromeric probe D15Z1. Using D1Z2, the yellow signal is translocated from 1p to 15p, but remains on 1p when using the cosmid probes. In all pictures, the der(1) is marked with an arrow.

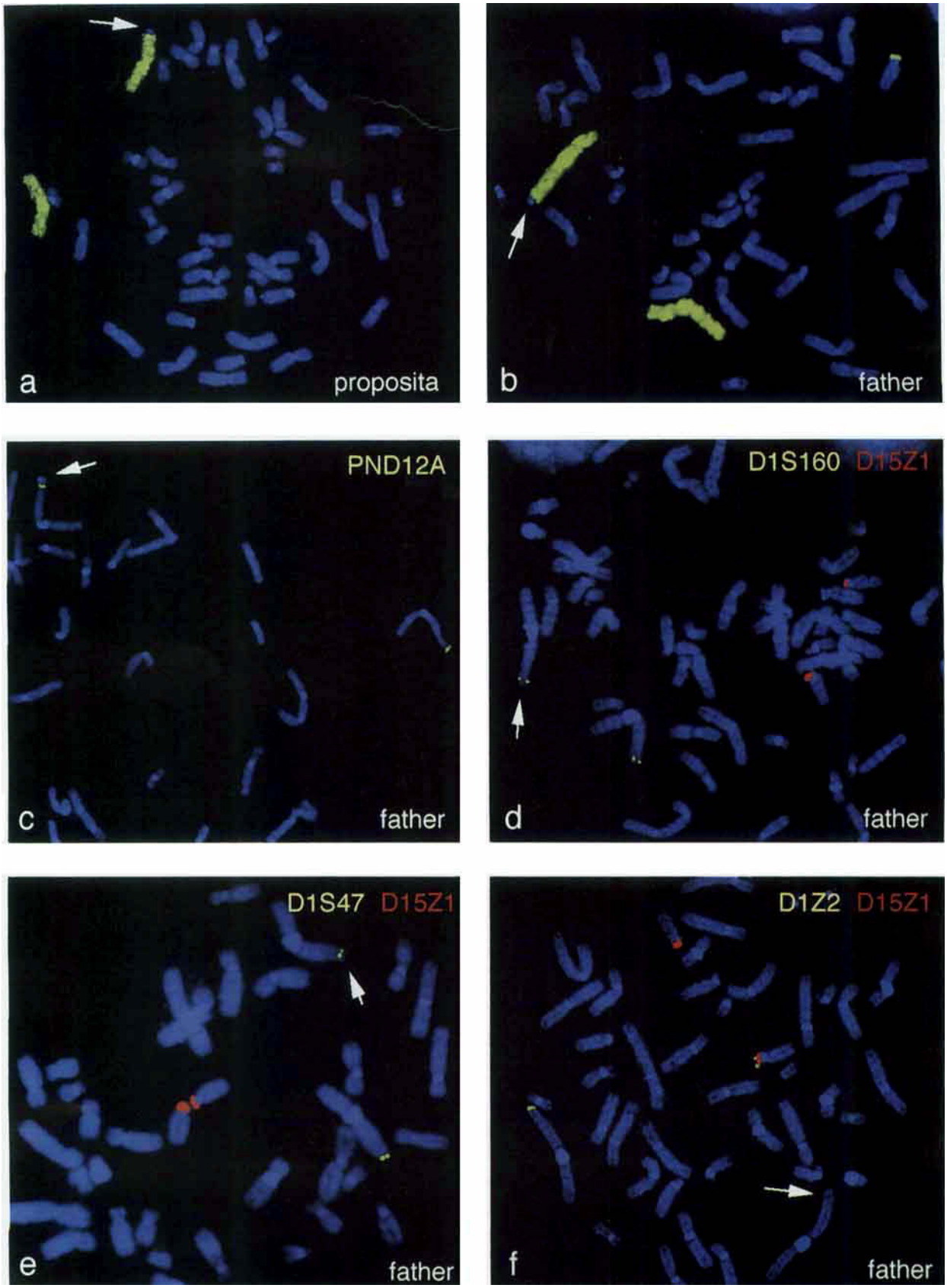
a
proposita
b
father
PND12A
c
father
D1S160 D15Z1
d
father
D1S47 D15Z1
e
father
D1Z2 D15Z1
f
father

Fig. 4.

TABLE I. Clinical Findings in Patients With Monosomy 1p36

	Hain et al., 1980		Yunis	Desangles	Steele	Abbas	Barbi	Keppler-Noreuil et al., 1995			Present
	Case 1	Case 2	et al., 1981	et al., 1983	et al., 1984	et al., 1990	et al., 1992	Case 1	Case 2	Case 3	case
Breakpoints	1p36 15q11	1p36 15q11	1p36 21p13	1p36 9p12	1p36.2 13p11.2	1p36 Yp	1p36.2 15p11.2	1p36.22	1p36.22	1p36.22	1p36.3 15p11.2
Psycho-motor retardation			Yes		Yes	Yes	Yes	Yes	Yes	Yes	Yes
Muscular tonus		Hypertonia	Hypotonia		Hypotonia	Hypotonia	Hypotonia	Hypotonia	Hypotonia	Hypotonia	Hypotonia
Growth			Retarded	Low birth weight	Normal	Retarded		Retarded	Retarded	Normal	Normal low birth weight
Eyes	Hyper-telorism		Deep set amaurotic	Hyper-telorism slant down	Deep set	Deep set	Deep set amaurotic slant up optic-atrophy	Small slant up	Small coloboma	Hyper-telorism	Deep set amaurotic optic atrophy
Ears	Low set square		Low set dysplastic post. rotated	Low set dysplastic post. rotated		Low set post. rotated	Low set dysplastic square	Low set preaur. pits	Low set small	Low set	Low set dysplastic post. rotated square
Nasal bridge		Prominent	Depressed	Flat	Prominent	Flat wide	Wide	Depressed		Depressed	Depressed
Forehead	Narrow tall					Frontal bossing	Prominent	Frontal bossing			Frontal bossing
Occiput		Prominent	Flat			Flat				Flat	Flat
Cleft lip/ palate			Yes	Yes			Yes	No	No	No	No
Heart	Cardio-megaly	Cardio-megaly	Infun-dibular stenosis of right ventricle	Cardio-megaly				Cardio-myopathy			Normal
Seizures		Yes			Yes			Yes	Yes	Yes	Yes
Hydro-cephalus/ vent. dilatation	Yes					Yes		Yes	Yes		No

Although distal to D1S47 and D1S160, commonly involved in neuroblastoma with 1p deletions, the present deletion may still be overlapping with the distal neuroblastoma locus described in tumors and cell lines [Amler et al., 1995; Caron et al., 1995; Cheng et al., 1995]. However, it was recently suggested that this distal suppressor gene is subjected to genetic imprinting as 16 of 17 allelic losses in tumors have been found to be of maternal origin [Caron et al., 1995]. This indicates that the maternal allele is normally expressed in these cells, while the paternal allele is silent. Consequently, in the present case, the loss of such a paternal allele would not increase the risk of developing neuroblastoma. Careful clinical, biochemical, and imaging examinations [Brodeur et al., 1993] have not disclosed any signs of neuroblastoma up to 3$^{6}/_{12}$ years of age, when the proposita was last examined. As a constitutional deletion is expected to predispose to early tumor development, the data presented support the conclusion that the present child has no increased risk of developing neuroblastoma.

This report shows the prognostic value of detailed FISH characterization of the chromosome defect. The results will also be of great help should prenatal diagnosis be needed in the future. Together with the case reported by Barbi et al. [1992], this is the smallest constitutional terminal deletion of 1p36 that has been reported. The clinical report will help to delineate the phenotype associated with this syndrome and the detailed analysis of the breakpoint gives additional information that may be used to further specify the location of the neuroblastoma tumor suppressor gene(s) located in 1p36.

ACKNOWLEDGMENTS

We thank Lena Ljöstad and Lena Tudegård for expert technical assistance, Dr. Garrett Brodeur and Dr. Ghislain Opdenakker for providing the locus-specific probes and Dr. Tommy Martinsson for valuable discussions. This work was supported by The Swedish Cancer Fund, The Swedish Medical Research Council, and the Swedish Child Cancer Fund.

REFERENCES

Abbas N, Novelli G, Stella NC, Triolo O, Corrado F, Fellous M, Chery M et al. (1990): A 45,X male with molecular evidence of a translocation of Y euchromatin onto chromosome 1. Hum Genet 86:94–98.

Amler LC, Corvi R, Praml C, Savelyeva D, Le Paslier D, Schwab M (1995): Reciprocal translocation at 1p36.2/D1S160 in a neuroblastoma cell line: Isolation of a YAC clone at the break. Eur J Cancer 31A:527–530.

Barbi G, Kennerknecht I, Klett C (1992): Reciprocal translocation t(1;15)(p36.2;p11.2): confirmation of a suggestive cytogenetic diagnosis by in situ hybridization and clinical case report on resulting monosomy (1p). Am J Med Genet 43:722–725.

Bello MJ, de Campos J, Kusak ME, Vaquero J, Sarasa JL, Pestana A, Rey JA (1994): Allelic loss at 1p is associated with tumor progression of meningiomas. Genes Chrom Cancer 9:296–298.

Biegel JA, White PS, Marshall HN, Fujimori M, Zackai EH, Scher CD, Brodeur GM et al. (1993): Constitutional 1p36 deletion in a child with neuroblastoma. Am J Hum Genet 52:176–182.

Brodeur GM, Pritchard J, Berthold F, Carlsen NL, Castel V, Castleberry RP, De Bernardi B et al. (1993): Revisions of the international criteria for neuroblastoma diagnosis, staging, and response to treatment. J Clin Oncol 11:1466–1477.

Buroker N, Bestwick R, Haight G, Magenis RE, Litt M (1987): A hypervariable repeated sequence on human chromosome 1p36. Hum Genet 77:175–181.

Caron H, van Sluis P, van Hoeve M, de Kraker J, Bras J, Slater R, Mannens M et al. (1993): Allelic loss of chromosome 1p36 in neuroblastoma is of preferential maternal origin and correlates with N-myc amplification. Nat Genet 4:187–190.

Caron H, Peter M, van Sluis P, Speleman F, de Kraker J, Laureys G, Michon J et al. (1995): Evidence for two tumor suppressor loci on chromosomal bands 1p35-36 involved in neuroblastoma: one probably imprinted, another associated with N-myc amplification. Hum Mol Genet 4:535–539.

Cheng NC, Van Roy N, Chan A, Beitsma M, Westerveld A, Speleman F, Versteeg R (1995): Deletion mapping in neuroblastoma cell lines suggests two distinct tumor suppressor genes in the 1p35-36 region, only one of which is associated with N-myc amplification. Oncogene 10:291–297.

Desangles F, Mourrieras P, Papouin-Rauzy M, Saliou P (1983): Monosomie 1pter par translocation familiale (1p;9p). Ann Genet 26:53–55.

Engelstein M, Hudson TJ, Lane JM, Lee MK, Leverone B, Landes GM, Peltonen L et al. (1993): A PCR-based linkage map of human chromosome 1. Genomics 15:251–258.

NIH/CEPH Collaborative Mapping Group (1992): A comprehensive genetic linkage map of the human genome. Science 258:67–86.

Hain D, Leversha M, Campbell N, Daniel A, Barr PA, Rogers JG (1980): The ascertainment and implications of an unbalanced translocation in the neonate: Familial 1:15 translocation. Aust Paediatr J 16:196–200.

Howard PJ, Porteus M (1990): Deletion of chromosome 1p: A short review. Clin Genet 37:127–131.

Howard-Peebles PN, Black SH (1994): FISH identification of deletion 1p36 from a half-cryptic maternal translocation. Am J Med Genet 52:381, abstract C14.

Keppler-Noreuil KM, Carroll AJ, Finley WH, Lane Rutledge S (1995): Chromosome 1p terminal deletion: report of new findings and confirmation of two characteristic phenotypes. J Med Genet 32:619–622.

Laureys G, Speleman F, Opdenakker G, Benoit Y, Leroy J (1990): Constitutional translocation t(1;17)(p36;q12-21) in a patient with neuroblastoma. Genes Chrom Cancer 2:252–254.

Laureys G, Speleman F, Versteeg R, van der Drift P, Chan A, Leroy J, Francke U et al. (1995): Constitutional translocation t(1;17)(p36.31-p36.,13;q11.2-q12.1) in a neuroblastoma patient: Establishment of somatic cell hybrids and identification of PND/A12M2 on chromosome 1 and NF1/SCYA7 on chromosome 17 as breakpoint flanking single copy markers. Oncogene 10: 1087–1093.

Magenis RE, Sheehy R, Lacey D, Brown MG, Litt M (1987): Small terminal deletion of chromosome 1 short arm in an infant with multiple anomalies: Confirmation by in situ hybridization of probe p1-79. Am J Hum Genet Suppl 41:A130.

Martinsson T, Sjöberg R-M, Hedborg F, Kogner P (1995): Deletion of chromosome 1p-loci and microsatellite instability in neuroblastomas analyzed with genetically mapped short-tandem repeat polymorphisms. Cancer Res, 55:5681–5686.

Reish O, Berry SA, King RA, Hirsch B (1994): Partial monosomy of chromosome 1p36.3: A distinctive phenotype. Am J Hum Genet Suppl 55:659.

Schleiermacher G, Peter M, Michon J, Hugot J-P, Vielh P, Zucker J-M, Magdelénat H et al. (1994): Two distinct deleted regions on the short arm of chromosome 1 in neuroblastoma. Genes Chrom Cancer 10:275–281.

Steele MW, Wenger SL, Geweke LO, Golden WL (1984): The level of 6-phosphogluconate dehydrogenase (6-PGD) activity in a patient with 1p terminal deletion suggests that the gene locus is not distal to sub-band p36.3 on chromosome 1. Clin Genet 25:59–62.

Takeda O, Homma C, Maseki N, Sakurai M, Kanda N, Schwab M, Nakamura Y et al. (1994): There may be two tumor suppressor genes on chromosome arm 1p closely associated with biologically distinct subtypes of neuroblastoma. Genes Chrom Cancer 10:30–39.

van der Drift P, Chan A, Laureys G, van Roy N, Sickmann G, den Dunnen J, Westerveld A et al. (1995): Balanced translocation in a neuroblastoma patient disrupts a cluster of small nuclear RNA U1 and tRNA genes in chromosomal band 1p36. Genes Chrom Cancer 14: 35–42.

van Roy N, Laureys G, Versteeg R, Opdenakker G, Speleman F (1993): High-resolution fluorescence mapping of 46 DNA markers to the short arm of human chromosome 1. Genomics 18:71–78.

Versteeg R, Caron H, Cheng NC, van der Drift P, Slater R, Westervelt A, Voûte PA et al. (1995): 1p36: Every subband a suppressor? Eur J Cancer 31A:538–541.

Wexler P, Gilfillan T, McGavran L, Sujansky E (1991): Deletions (1)(p36.3) and the potential role of high resolution chromosome analysis. Am J Hum Genet Suppl 49:278.

Yunis E, Quintero L, Leibovici M (1981): Monosomy 1pter. Hum Genet 56:279–282.